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PRELIMINARY EVALUATION OF POWDER PACKS

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DECEMBER 1987

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Powder packs - small packages of fire extinguishing powder - have been used to offer fire protection to fuel and hydraulic fluid containers. Two types of fire extinguishing powder were used successfully. The powder packs, from 3.2 to 25.4 mm thick, were placed around and in contact with the hydrocarbon containers.

An attacking shaped-charge jet had to pass through one powder pack before striking the container and then pass through a second powder pack as the jet exited the container. It was anticipated that the powder released by the event would mix with the fluid spray and vapors to render them non-flammable.

The results of experiments showed that under the correct conditions the powder packs could offer adequate fire protection. However, it was necessary to strengthen fluid containers to limit the amount of spray and vapors so that the initial fireball could be controlled.

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1. INTRODUCTION

Many flammable items are carried aboard ground combat vehicles. One type of flammable of concern is liquid hydrocarbons. Two of the largest, by volume, normally carried on vehicles are diesel fuel and hydraulic fluid. A fire initially involving either of these may lead to destruction of the vehicle and injury to crew members. In order to assure protection to both vehicle and crew, it is necessary to extinguish fires initiated by ballistic attack in the sub-second timeframe. One possible method of achieving this rapid extinguishment is by the use of powder packs. These are containers of fire extinguishing powder which could be used to surround the fuel cells and hydraulic reservoirs of vehicles.

The concept of protecting fuel cells with panels of fire extinguishing powder originated with aircraft.[1] The U.S. Army currently has plans to equip helicopters with powder containing panels to prevent combat induced fuel fires. Panels containing less than 2 mm thickness of powder will be attached to the exterior portions of the fuel cells to prevent fires when the cells are struck by small exploding projectiles. A projectile must first strike the panel before getting to the fuel cell. It has been demonstrated in aircraft tests that the powder will quench the initial fire. When the round functions, fuel and fire extinquishing powder are released to interact with the fireball from the explosive. The initial fuel fire is quenched. As long as there is no sustained ignition source there will be no reignition and no fuel fire, even though there may be a large fuel spill.

Our purpose is to investigate the possibility of applying this new technology of powder packs to the prevention of hydrocarbon fires in Army ground vehicles. The vehicle which was simulated for testing the concept was the Field Artillery Ammunition Support Vehicle (FAASV). This vehicle carries large quantities of ammunition to resupply artillery units. The ammunition represents a very large percentage of the presented area of the crew compartment in this vehicle. It is assumed that a hit on the ammunition will lead to destruction of the vehicle since no ammunition fire/explosion countermeasures are present. There is a relatively small probability of a penetration which involves the crew volume and hydrocarbon fluids but not any ammunition. The BRL weighted estimate for the probability of a hydrocarbon fire (but no ammunition involvement) in the crew volume, given a penetration, is approximately 6%.[2] Therefore, there is not a large hydrocarbon fire threat in this vehicle. However, even this small fire probability cannot be ignored. Fire protection must be provided for the crew and vehicle.

For our work, a shaped-charge device containing approximately 700 grams of high explosive material was taken as a threat comparable to that of a shoulder fired rocket which would be employed in a battlezone. This device contains much more explosive than do the small exploding rounds that the powder containing panels were designed to protect against. In addition, the jet formed by the shaped-charge device represents a very different kind of threat than does a round which carries just explosive. Therefore, we could not assume that the technology developed for aircraft could

be easily applied to the FAASV. The powder pack concept had to be established as a viable method of fire protection in a ground vehicle. Therefore, experiments were conducted using a test setup with important features similar to those found in the FAASV to demonstrate the possibility of quenching hydrocarbon fires caused by shaped-charge attack on both fuel and hydraulic fluid. The current U.S. Army requirement is that fuel fires due to weapon attack be extinguished in crew occupied compartments within 250 milleseconds after attack. This rapid quenching of fuel fireballs should protect crewmembers from burn injuries.

2. EXPERIMENTAL

2.1 Materials. The initial concern was with a choice of a fire extinguishing powder. We decided to use only conventional fire extinguishing powders commonly accepted as non-toxic. This would minimize any possible objections relating to exposure of crew members to the powder. Two widely used and effective fire extinguishing powders are potassium bicarbonate and Monnex®.* The former is also a general purpose food additive as well as being a recognized antacid. Monnex® is a fire extinguishing powder made from potassium bicarbonate and urea. It is sold by ICI of America. Both of these fire extinguishing powders have been used successfully in our work.

For initial tests, fire estinguishing powder was simply placed into plastic bags inside a wooden framework. The plastic bags were held in place by wire screening. The frames were then taped to the fuel containers.

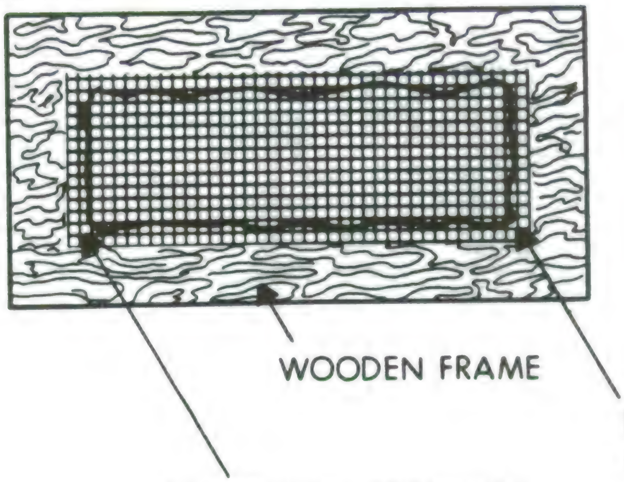
In later tests potassium bicarbonate powder was poured into the void spaces of aluminum honeycomb material. The honeycomb was chosen as a method of preventing the powder from settling to the bottoms of vertical packs. The packs were taped to the sides of hydraulic reservoir setups. The honeycomb used ranged from 3 mm to 25.4 mm thick. Aluminum was chosen since it was readily available, but a non-burning material (such as Kevlar) would be preferable.

Aluminum foil has been used to cover all sides of the honeycomb powder packs. Appropriate pieces of tape have been used to seal the aluminum foil around the powder filled honeycomb. Schematics of the powder packs are given in Figure 1.

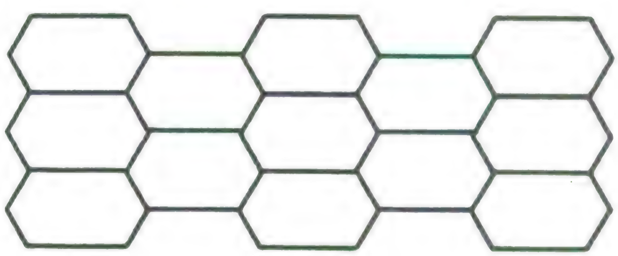
The fuel of interest is hot diesel fuel. In our tests, cold (room temperature) gasoline was used to simulate hot (77°C) diesel fuel. Tests at the Ballistic Research Laboratory have shown that hot diesel fuel is as flammable as cold gasoline.[3] Post test clean-up is much easier if gasoline is used in place of diesel fuel. The gasoline we used was conventional unleaded gasoline of the type used in government administrative vehicles.

*Monnex is a registered trademark of the ICI Corporation. It is a carbamic powder formulated from the reaction product of potassium bicarbonate and urea.

POWDER PACK A



POWDER PACK B



ALUMINUM HONEYCOMB FILLED WITH POWDER AND COVERED TOP, BOTTOM AND SIDES WITH ALUMINUM FOIL

Figure 1. Schematics of Powder Packs

Two types of hydraulic fluid were used in these tests. The first was a fire resistant hydraulic (FRH) fluid which has a flash point of about 220°C. It meets a Mil Spec 46170. This material will not pool burn (a spill does not burn), but it will burn as a spray.[4] The second type of hydraulic fluid which we used meets a Mil Spec 6083. It has a minimum flash point of 93°C. When hot, it will pool burn (a spill can burn). It will also readily burn as a spray.

BRL precision shaped-charges (81 mm cone diameter) were taken as realistic threats to the vehicle. These shaped-charges consist of a 42° copper cone surrounded by 681 grams of Composition B explosive. A booster and detonator are employed to activate the devices. In our experiments, the bare version of the shaped charge was used. There were no aluminum housings around the explosive. In all our tests, the shaped-charges were set at two cone diameters from the conditioning armor (25.4 mm thick aluminum). At this stand-off the penetration of the copper jet is approximately 400 mm into rolled homogeneous armor (steel).

2.2 Setups.

The fuel system of interest consists of a 25.4 mm thick aluminum armor plate protecting a fiberglass fuel cell which contains hot diesel fuel. A very interesting point is that the fuel cell is not actually in the crew compartment of the vehicle we are simulating. The cell is backed up by a 6 mm thick aluminum plate which is the actual wall of the crew compartment. We are interested in preventing (or quickly extinguishing) any fuel fire in the crew compartment, which is on the far side of the 6 mm thick plate. Therefore, given a ballistic attack, only the fuel spray which comes through any perforations in this plate can reach the crew compartment.

To simulate this geometry we used a heavy-walled five gallon (19 liter) drum made of polyethylene. A 25.4 mm thick aluminum plate was placed on the top flat side of the drum. A 6 mm thick aluminum plate was placed on the bottom flat side of the drum. A wooden frame containing a plastic bag with a 25.4 mm thickness of fire extinguishing powder was taped to the thin aluminum plate. After a gap of 736 mm, a 25.4 mm aluminum plate was positioned so that it was in line with the center of the polyethylene fuel container. This last aluminum plate served as a splash surface for the shaped-charge jet which was employed for ballistic attack. The burning aluminum which erodes from the plate as a jet passes through serves as the primary ignition source for the fuel spray.

For each of our fuel tests, a BRL precision shaped-charge device was placed two cone diameters (162 mm) from the 25.4 mm thick aluminum plate. When the device was activated, a copper jet passed through the 25.4 mm of aluminum, then through the 19 liter plastic container of gasoline then through the 6 mm aluminum plate, then through fire extinguishing powder. Gasoline spray and fire extinguishing powder followed the direction of the jet. The jet passed through 737 mm of air and then struck a final 25.4 mm aluminum plate. A cloud of burning aluminum particles was released and served as an ignition source for the gasoline spray. We were

concerned with the measurement of the timespan during which the gasoline spray burned in the 737 mm air gap of our setup. This air gap represents the interior portions (crew compartment) of the simulated vehicle. Both standard video and motion-pictures, at 200 frames per second, were recorded for each test. These were analyzed to provide the duration of the fuel fire in the simulated interior of the vehicle. No measurements were made of the fire on the other side of the 6 mm aluminum plate, since this was outside the simulated crew compartment and no fire protection was provided for this portion of the experimental setup. A schematic of the experimental setup is provided in Figure 2.

The hydraulic fluid reservoirs used in these experiments were steel units with a nominal capacity of 53 liters. With this volume of fluid, there is a 51 mm vapor gap (ullage) between the liquid surface and the top of the reservoir. Four bolts attached the reservoir to a steel platform inside a 7 cubic meter steel test chamber.

The experimental procedure called for firing shaped-charge jets through 25.4 mm of conditioning aluminum armor into the reservoirs of hot hydraulic fluid. From past experience with fuel fires, it was realized that if the amount of fluid spray could be held to a minimum, there would be less chance of a sustained fire than if there were a large fluid spray and a rapid loss of fluid from the reservoirs. Therefore, the decision was made to reinforce the reservoirs to minimize the amount of spray which would follow the jets from the reservoirs.

In most cases, a 6 mm thick, four-sided mild steel box was placed around the reservoirs. It was felt that the reservoirs required no reinforcement on the bottoms, since they rested on a steel shelf. The tops of the reservoirs would not require reinforcement if sufficient ullage were available between the top of the liquid and the top of the reservoir. Past experience indicated that at least 100 mm of ullage would be required to prevent failure of the tops of the reservoirs. This amount of ullage was used for all hydraulic fluid tests. The capacity of the reservoirs was reduced to 48 liters since we left more ullage than the manufacturer had anticipated. The steel boxes were made oversized so that sheets of energy absorbing rubber from 6 to 13 mm thick could be inserted on all four sides between the reservoirs and the boxes. This arrangement served to strengthen the reservoirs and limit the amount of hydraulic fluid which could be ejected from the setups as a spray. Powder packs were attached to the steel boxes (or, if no boxes were used, to the reservoirs themselves) on both the jet entrance and jet exit sides.

A 6 mm diameter steel rope was used to tie down the reservoirs to the test chamber wall for our initial tests. This was to ensure that the reservoirs remained in place after attack by shaped-charge jets. For the last three tests, no rope was used and the reservoirs stayed in place.

Twenty-five millimeter aluminum armor plates were placed 1618 mm beyond the reservoirs in the paths of the jets. The burning aluminum eroded from the plates served as ignition sources for the hydraulic fluid spray. A schematic of this setup is given in Figure 3.

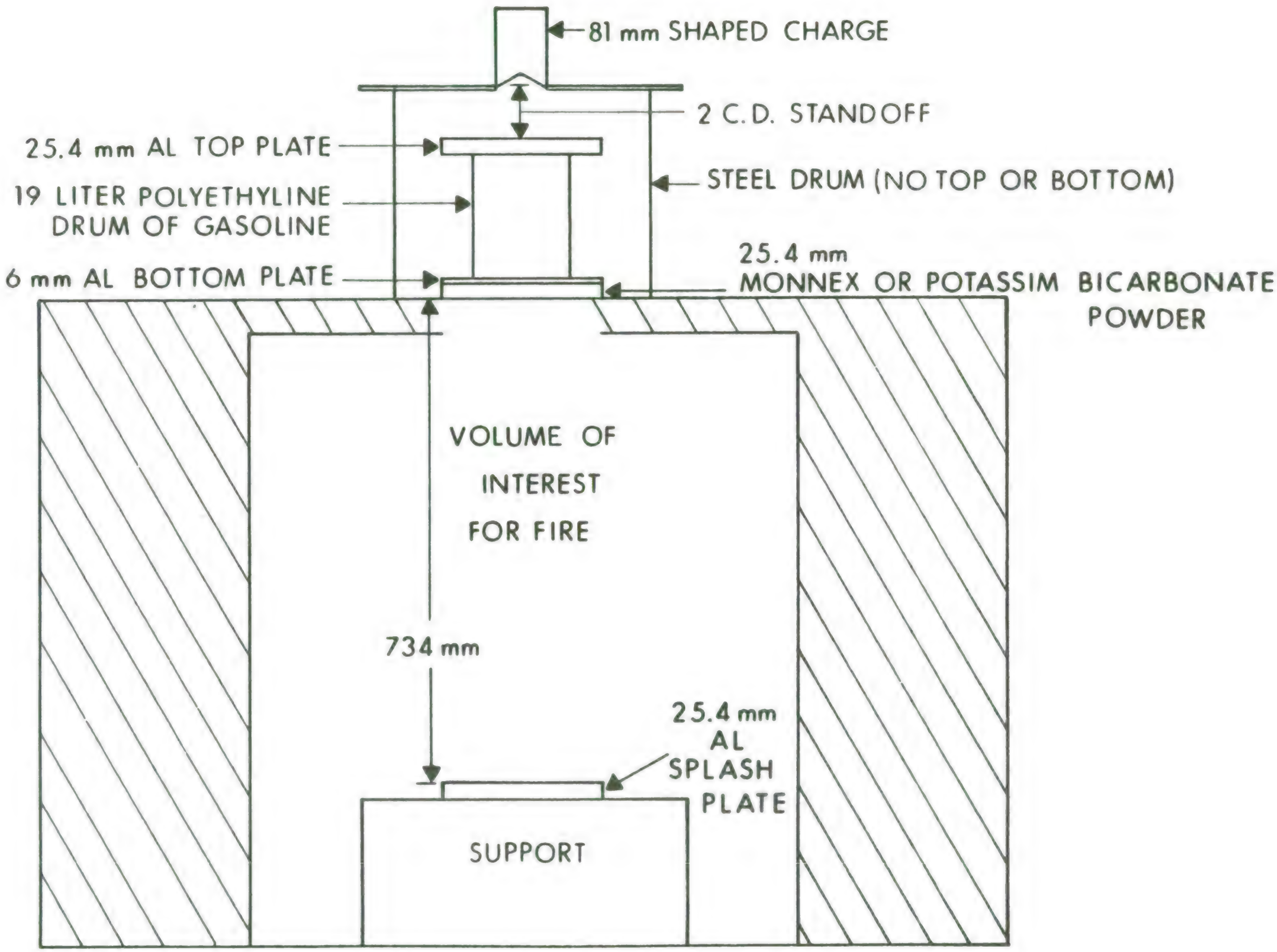


Figure 2. Schematic of Setup Used in Fuel Tests

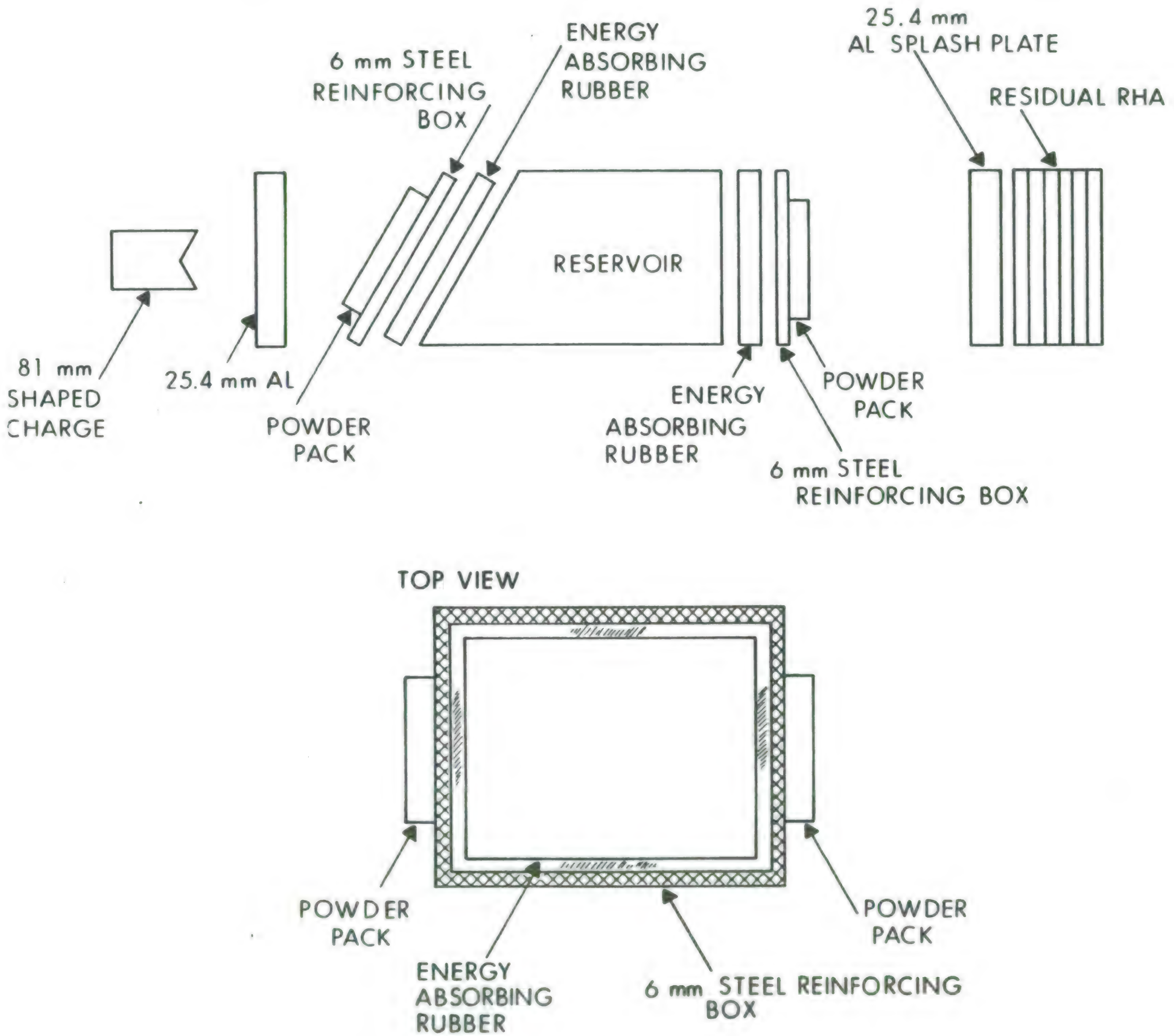


Figure 3. Schematic of Setup Used in Hydraulic Fluid Reservoir Tests

Motion pictures (200 frames per second) and a conventional video recorder (30 frames per second) were used to record the events. These records were analyzed to determine the maximum time of burning of the hydraulic fluid spray.

3. RESULTS

3.1 Simulated Fuel System. Three experiments were conducted to establish the applicability of the powder pack concept in extinguishing fuel fires. Two different fire extinguishing powders were used in addition to a base line test in which no attempt was made to extinguish the fire. Table 1 presents the results of these experiments which used the setup presented in Figure 2.

Both Monnex® and potassium bicarbonate powders were shown to be useful in quenching the fuel fires. Both powders were capable of reducing the final burn time by about one-half, compared to an identical test setup with no fire extinguishing powder. It is interesting that the intensity of the aluminum burn was strongly attenuated in the presence of the powder. The powder was not visible in the records (video and motion picture film) until about 1 second after firing the shaped-charge device. The cloud of aluminum typically burns out in 100 milliseconds or less. This argues against a simple obscuration of the light from the burning aluminum. It is possible that the particles of aluminum became coated by the powders and burned poorly. If this is true, the cloud of burning aluminum would become a poor ignition source in the presence of the powders.

3.2 Hydraulic Reservoirs. For the initial test with powder packs on the hydraulic reservoir, we chose conditions most likely to bring a success. We reasoned that if fire could not be quenched in 250 milliseconods under very favorable conditions, it would be a strong indication that powder packs would not be a suitable way of preventing fire when a shaped-charge jet attacks a hydraulic fluid reservoir. Therefore, FRH fluid at 77°C was used in place of 6083 fluid. The reservoir was reinforced by addition of a 6 mm steel box and energy absorbing rubber. Two 25.4 mm thick powder packs of potassium bicarbonate were used. The first was at the jet entrance side of the reservoir, and the second was at the jet exit side.

Video records indicated that the fire, due to hydraulic fluid spray, was quenched in about 167 milliseconds. There was a very large and persistant cloud of powder. The cloud obscured vision on the motion picture film right from the start of the event. It appeared that more powder was released more quickly than in the fuel tests. This may be due to the use of powder packs at both the jet entrance and exit sides for the hydraulic fluid tests. In the fuel tests, only exit side powder packs had been used. Fortunately, the interior of the chamber was visible on the video records. This may be due to the different angle of the cameras. The powder packs performed well in extinguishing fire for the first case.

For the second experiment, we looked for conditions which would be favorable in causing a fire which would last over 250 milliseconds. Conventional hydraulic fluid (6083) was used at 77°C. The steel reinforcing box was used, along with the energy absorbing rubber. Powder packs

Table 1. Results of Using Powder Packs to Extinguish Fuel Fires

Threat	Conditioning Armor	Fuel Container	Fuel	Restraining Plate (to hold fuel container)	Splash Plate	Powder	Results
81 mm shaped charge	25.4 mm aluminum	Polyethylene	19 liters gasoline	6.4 mm aluminum	25.4 mm aluminum	None	Fuel fire lasted over 300 ms visibility lost for 18 seconds
81 mm shaped charge	25.4 mm aluminum	Polyethylene	19 liters gasoline	6.4 mm aluminum	25.4 mm aluminum	25.4 mm Monnex®	Fuel fire lasted 200 ms visibility lost for 20 seconds
81 mm shaped charge	25.4 mm aluminum	Polyethylene	19 liters gasoline	6.4 mm aluminum	25.4 mm aluminum	25.4 mm potassium bicarbonate	Fuel fire lasted 150 ms visibility lost for 8 seconds

®Trademark of ICI Corporation

only 3 mm thick were used at both the jet entrance and exit sides, on the outside of the steel reinforcing box. These very thin packs of potassium bicarbonate were capable of extinguishing the hydraulic fluid fire in 233 milliseconds from the video records. Even in this case, there was a cloud of powder released so quickly that it obscured the view on the motion picture film.

The third experiment was designed to establish the importance of the powder packs themselves. Since there was only a limited amount of spray from the setup (due to the small holes in the reinforcing boxes) we needed to test whether or not the powder packs were even necessary to achieve a fire out time of 250 milliseconds. Therefore, 6083 hydraulic fluid at 77oC was used in a reinforced reservoir (6 mm steel box plus rubber). No powder packs were used with this setup. The fire out time, from video, was 363 milliseconds. This showed that, even with a reinforced reservoir, the powder packs are required if we are to quench hydraulic fluid fires in 250 milliseconds or less.

The fourth experiment was intended to show the roll of the reinforcing box. Hot 6083 hydraulic fluid was used in a normal reservoir. No reinforcing box or energy absorbing rubber was used. Two 12.7 mm powder packs of potassium bicarbonate were used. One was at the jet entrance side of the reservoir, the other was at the jet exit side. Video records showed that the fire was not quenched until about 530 milliseconds. This result indicates that when a large quantity of fluid spray is expelled from the reservoir, it can overwhelm the powder pack extinguishers. Therefore, it is necessary to reinforce the reservoir as well as to utilize powder packs.

The data on hole size in the reservoir caused by the shaped-charge jets are given in Table 2. It can be seen from these data that, when no reinforcement is used, the reservoir suffers more damage. What is probably even more important is that the jet holes in the reinforcing boxes were only about 6 mm in diameter. This is probably the most important thing in limiting the amount of fluid which sprays out of the setup.

In one test, the reservoir was filled with a solid reticulated foam material.* Neither a reinforcing box nor energy absorbing rubber was used, although 12.7 mm thick powder packs were employed. Yet the fire was time of 55 ms was the shortest of any measured in this series of tests. A possible explanation is that the reticulated foam may have impeded the rapid flow of fluid towards the holes in the reservoir, limiting the amount of fluid spray. A reduction in the amount of spray would be very important in reducing the duration of the fire.

As mentioned in the section on experimental setups, a 100 mm ullage space was left in the reservoirs. Slight bulges were observed in the tops of 2 of the reservoirs after tests. This is interpreted as meaning that 100 mm ullage is the minimum required with this level of attack. A larger ullage would probably be required if a higher level of attack (larger shaped charge) is used to attack a reservoir.

*Reticulated foam is flexible polyurethane foam produced by the Scott Paper Company.

Table 2. Hole Sizes in Reservoirs and Powder Packs

Thickness Powder Packs	Reinforcement Steel Box Plus Rubber	Reservoir Entrance Hole	Reservoir Exit Hole	Hole Size in Honeycomb of Powder packs (for Two Packs)
None used	Yes	480 sq mm	2 holes 130 sq mm and 120 sq mm	N/A
None used	Yes	790 sq mm	2 holes 290 sq mm and 280 sq mm	N/A
None used	No	1290 sq mm	2580 sq mm	N/A
3.2 mm	Yes	1270 sq mm	2 holes each 130 sq mm	25800 sq mm
12.7 mm	No	2580 sq mm	2 holes 480 sq mm and 200 sq mm	36500 sq mm
12.7 mm	No but reservoir filled with retriculated foam	2420 sq mm	3 exit holes 50 sq mm, 280 sq mm and 130 sq mm	15500 sq mm
25.4 mm	Yes	300 sq mm	2 holes 390 sq mm and 130 sq mm	16200 sq mm

Data on fire out time and time to regain visibility through the powder are given in Table 3. It is interesting that even when no powder packs were used several seconds of visibility were lost just because of the general conditions that prevail when a shaped-charge jet attacks the reservoir in a chamber.

It was thought useful to compare the amount of potassium bicarbonate ejected into the chamber to quench the fire to the amount of other fire extinguishing agents which would be required to quench flames. These data are given in Table 4. It is very interesting to see that although Halon 1301 is considered to be an extremely efficient extinguishing agent, considerably more Halon 1301 is required to quench fires than some of the more efficient powder extinguishing agents. It is noteworthy that very little powder is ejected from the 3 mm thick packs. There simply is not enough powder to render the entire volume of the test chamber non-flammable. In all probability, the reason the powder performs so well is that it is ejected along the path of the shaped-charge jet, along with the fluid spray. The powder is concentrated where it is needed, right with the spray.

4. DISCUSSION

Our tests indicate that under the right conditions, it is possible to extinguish fires from hydrocarbon sprays in 250 milliseconds or less. It appears necessary (or at least very desirable) to limit the amount of fluid which sprays out of the holes caused by the passage of a shaped-charge jet through the reservoir. The simple powder packs rely on the energy from the jet to break the packs open and eject the powder. If the damage to the fluid container is so great that a large amount of spray is involved, then it might be necessary to modify the powder packs to actively eject the powder. However, if a means can be found to limit the amount of spray (by reinforcement, by use of a filler material, such as reticulated foam, or by a redesign of the container), then that would be perferred to an active method of disseminating the powder. As more data become available, the advantages of the various approaches should become clearer.

The loss of visibility in the test chamber is of some concern. The use of powder packs in a vehicle could result in a similar loss of visibility and confusion to crew members if the vehicle is struck in combat. However, the present automatic fire suppression systems which use Halon 1301 also cause a similar loss of visibility due to formation of smoke or fog when the agent quenches the fire.[5] With either Halon 1301 or powder packs it would be desirable to have the ventilation system remove the agent from the vehicle as quickly as possible.

A point which has not been addressed is the compatibility of Halon 1301 with powder packs in the same vehicle. If powder packs should be used to increase the capability of a Halon 1301 system in an existing vehicle, it is quite possible that both systems could function at the same time. While we do not think that there would be any new problems associated with the simultaneous use of both systems, this situation should be addressed.

Table 3. Duration of Hydraulic Fluid Fires Caused by Shaped-Charge Jet Impact

Fluid	Reinforcement Steel Box Plus Rubber	Thickness of Powder Packs (front and rear)	Fire Duration	Loss of Visibility
48 liters FRH[A] @ 77°C	No	None	924 ms	3 seconds
48 liters FRH[A] @ 77°C	Yes	None	820 ms	5 seconds
48 liters FRH[A] @ 77°C	Yes	25.4 mm	165 ms	18 seconds
48 liters Mil 6083[B] @ 77°C	No	12.7 mm	533 ms	7 seconds
48 liters Mil 6083[B] @ 77°C	Yes	None	363 ms	9 seconds
48 liters Mil 6083[B] @ 77°C	No but reservoir filled with retriculated foam	12.7 mm	55 ms	4 seconds
48 liters Mil 6083[B] @ 77°C	Yes	3.2 mm	231 ms	5 seconds

[A] Fire Resistant Hydraulic Fluid - flash point approximately 218°C

[B] Conventional Hydraulic Fluid - flash point 93°C minimum

Table 4. Amount of Agent Required to Quench Fire

Agent	Concentration
Halon 1301 (5% in air)	333 mg/liter
Monnex®[A]	70 mg/liter
$KHCO_3$[B]	75 mg/liter
$NaHCO_3$[C]	100 mg/liter
Two 25.4 mm thick potassium bicarbonate powder packs in 7 cubic meter chamber	70 mg/liter
Two 3 mm thick potassium bicarbonate powder packs in 7 cubic meter chamber	11.4 mg/liter

[A]Information obtained from Kent Ewing of Naval Research Labaoratory

[B]Potassium bicarbonate

[C]Sodium bicarbonate

It is even possible that, since potassium bicarbonate, the material of choice for our powder packs, is basic, it could neutralize the acid products produced by the interaction of Halon 1301 with flames. This would make Halon 1301 even more useful in crew compartments. However, this neutralization must be demonstrated.

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